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Perspectives on the nexus between good risk communication and high scientific risk analysis quality

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A B S T R A C T

In general, successful risk communication can be said to require "an understanding of the target audience, including the best means for reaching the audience: a credible or trusted source; and a message that has ideally been pre-tested to ensure its effectiveness" [43]. The scientific quality of the risk analysis is not questioned. The sources can be credible or trusted, but the scientific risk analysis quality can be poor. For example, the risk communication can be based on a scientifically unsound risk characterisation, yet be communicated successfully if the reference is a communication perspective as above. Good risk communication cannot, however, be seen in isolation from the broader process of risk analysis and management. The present paper provides some reflections on this topic, the main aim being to strengthen the argumentation for the thesis that scientific and foundational issues of risk analysis are critical for the successful communication of risk. Several examples are used to demonstrate this thesis.

1. Introduction

Think about a hypothetical case, where a risk assessment for a process plant is conducted by a recognised consulting company and the results are communicated to the public and the decision-maker. A key result is that the risk – expressed as a computed probability – is found acceptable, according to some defined criteria. The activity studied is judged to be safe. Dialogue and interaction among all relevant stakeholders are also conducted. All parties, including the decision-maker, consider the consultancy company to be a highly credible and trusted source and conclude from this that they have been adequately risk informed and the risk communication process has been solid and positive in all respects. All involved perceive the communication as successful.

As another example, consider the current risk and threat level characterisations in relation to security issues; see for example [44,34]. People are informed by the authorities that the threat level is low, the reference being a low-judged likelihood. It is probable that the police security services have a good basis for their judgements, and it can thus be argued that the risk communication is successful – people are adequately informed.

But are these perceptions and judgements really enough to conclude that the risk communication is successful? No the present paper argues; successful risk communication cannot be seen as separate from the scientific quality of the risk assessments and the risk characterisations. It is necessary to question the extent to which the risk assessment and the risk characterisation are in line with the scientific knowledge generated by the risk analysis field. Here, risk analysis is used in a broad sense, as done by the Society for Risk Analysis (SRA) since 1980, to include risk assessment, risk characterisation, risk communication, risk management, and policy relating to risk [41]. There will always be discussions about what is the current risk analysis scientific knowledge, yet it is important to acknowledge that some quality references exist that extend beyond individual perceptions. The analysis group members may be confident that they are applying appropriate risk analysis concepts, approaches, principles and methods, but this does not mean that this is in fact the case, as the reference is the risk analysis science.

For example, in the security example, it can be argued that risk communication based on likelihood judgement alone can mislead the public. The problem is that the strength of the knowledge supporting the judgement is not really covered by the likelihood judgements used to characterise and communicate the risk level, as will be thoroughly discussed in the coming sections of this paper.

As another example, consider climate-change-related risk and the associated risk communication of the Intergovernmental Panel on Climate Change (IPCC). For many people, the IPCC is indeed a credible and trusted source. Based on thorough analysis, involving a number of scientists, the IPCC has produced extensive characterisations of climate-change-related risk and uncertainties. However, from a risk analysis perspective, it can be argued that this risk communication is poor in many ways [8]. For example, the IPCC uses the likelihood/probability concept to express important findings, for instance that it is extremely likely (at least 95% probability) that most of the global warming trend is a result of human activities [20]. The IPCC does not, however, provide a clear understandable interpretation of the likelihood/probability concept. The consequences are that people read this type of statement in different ways and have difficulties in understanding what the

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probability really expresses: does it reflect fundamental variation in physical phenomena, differences in expert judgements, different views about specific issues or something else?

If we read the media interpreting the IPCC work, the impression is that the IPCC expresses that science states that global warming takes place and is a result of human activities; the uncertainties are very small and can be basically ignored: the experts are confident that the statements referred to are true. However, the IPCC reports stress that likelihood and confidence statements should not be mixed ("confidence should not be interpreted probabilistically" [19]). The 95% probability statement is of course also related to confidence, but the IPCC reports seem to indicate that this is not the case. Thus, a deeper look at the IPCC platform on risk and uncertainty reveals that the analysis has some serious weaknesses. Acknowledging these, can we still argue that the risk communication is successful?

Clearly, what successful means depends on what the reference is. The issue has been thoroughly discussed in the risk communication literature (e.g. [12,13,23,24,28,37,38,46]). Examples of risk communication objectives include: enlightenment function, right-to-know function, attitude change function, legitimation function, risk reduction function, behavioural change function, emergency preparedness function, public involvement function and participation function [38]. Increasing trust and credibility is often seen as a key objective of the risk communication, and trust and credibility are also prerequisites for many other objectives [38]. Trust and credibility depend on factors like perceived competence, objectivity (lack of biases in information as perceived by others), fairness (acknowledgement and adequate representation of all relevant points of view), consistency (predictability of arguments and behaviour based on past experience and previous communication efforts) and faith (perception of 'good will' in composing information) [38]. It is expected that the communicator conveys accurate, objective, and complete information.

There is, however, a potential gap between what is perceived as competence, objectivity, etc. and what the scientific field claims. In the above examples, the sources may be viewed as trusted and credible, yet the risk communication can be considered unsuccessful from a risk analysis perspective.

The present paper discusses this issue, the nexus between risk communication and the scientific quality of the risk analysis. Risk communication is understood as exchange or sharing of risk-related data, information and knowledge between and among different target groups (such as regulators, stakeholders, consumers, media, general public) [41,42]. The main aims are to achieve increased awareness of this issue, as it is considered under-focused on today, as well as to obtain new insights on risk communication's dependencies on the scientific and foundational issues of risk analysis. The paper is based on the conviction that current risk analysis practice is subject to many weaknesses of a conceptual and fundamental character, which have severe implications for the quality of the risk communication and risk management, as indicated by the above examples. Probability is a key concept in risk and uncertainty analysis, but lack of precision in the understanding and use of this concept hampers risk communication and management in many situations.

This discussion is not new. As commented by one of the reviewers of the original version of the present paper, the issue has been discussed since the time of the Rasmussen report on nuclear power [31]. A basic reference is the book 'Improving risk communication' developed by a Committee on Risk Perception and Communication of the US National Research Council [30], which provides a thorough discussion of what successful risk communication means. See also the excellent review papers by Bier [9,10]. In Europe we find similar discussions, see for example [35,36]. The issue was highlighted in the 90s in relation to the implementation of the Seveso-directive for industrial plants [39]. Some relevant references are [1,25,26,17], see also HSE [18]. A major concern was the quality of the risk assessments submitted to the authorities. As commented by this reviewer alternative solutions were considered, including use of accredited risk analysts and risk assessment standardisation.

The risk analysis field has developed considerably since then, and the present paper aims at performing an updated evaluation of the issue. As such it will provide new insights by highlighting what can be seen as current perspectives on risk and risk analysis. Compared to earlier works on the issue, the paper seeks to dive deeper into the fundamental features of risk analysis, not only risk assessment but all aspects of risk analysis as here defined. As requested by the reviewer, some reflections will also be made on the SRA principles: is it more likely that these will be more effective in influencing the field and in particular the risk communication than guidance provided by earlier attempts? See Section 3.4.

As discussed above, scientific quality is to varying degree addressed when the issue is how to perform successful risk communication. This does not mean, however, that scientific quality of the risk analysis, and in particular the risk assessments, is not addressed in many contexts. As commented by one of the reviewers of the original version of this paper, the quality of the assessment quickly becomes an issue among the stakeholders when the results of an assessment do not support their preferred course of future developments. It will then be a main goal to undermine the position of the opposite party. By making the quality and the science the subject, the discussion is placed in the realm of the scientists, away from the political arena. As long as "the scientists are discussing" there is no reason for the politicians to go into the intrinsically political aspects of their decision and thus show their hands.

The remainder of the paper is organised as follows. In Section 2 we review briefly what good (prudent) risk analysis is, as a basis for discussing what we mean by scientific quality. Section 3 provides the main contribution of the paper and discusses why scientific risk analysis quality is essential for ensuring good risk communication. The above examples are used to illustrate the discussions. These examples reflect the focus and interest of the author. They are of a fundamental character relevant for many types of applications. Finally, Section 4 presents some conclusions.

2. What is good risk analysis?

It is possible to formulate a set of principles which define what is good or prudent risk analysis. These principles can be seen as constituting the most warranted statements or justified beliefs that the risk analysis knowledge field can produce. The perspective is inspired by the understanding of science defined by Hansson [15]. This knowledge field is built on the totality of relevant educational programmes, journals, papers, researchers, research groups and societies, etc., addressing risk analysis. What are the most warranted statements (justified beliefs) is always an issue. There is a continuous 'battle' in respect of what these statements are – it is about institutions and power. Different directions and schools of thought argue for their beliefs, trying to gain control over the field [11].

For risk analysis, considerable work exists that provides input to this 'battle'. Every paper in a risk analysis journal that argues for the use of a specific concept, theory, principle, approach, method or model represents a contribution to this discussion of what the most warranted statements are. A specific scientific paper can be very influential for the field, such as Kaplan and Garrick's [22] paper, which provides recommendations on how to quantify risk. There are also many books that have had and are having a great impact on current understanding of what prudent risk analysis is. Examples include the monographs by Renn [37] and Haimes [14]. However, the impact is typically larger if a group of people – originating from different environments, such as standardisation organisations or societies – can derive some recommendations. As two examples, consider the ISO 31000 Guidelines for risk management [21] and the SRA document on risk analysis principles [43].

ISO [21] is developed in accordance with the ISO process, which

involves representatives from a large number of countries. The process is not a scientific process, as the document produced is not generated by means of a scientific process. The authors are not necessarily scientists in the field. There is no open scientific discourse on the choices made. Yet, the documents strongly influence the practice of risk analysis.

The SRA [43] document has been established by senior scientists in risk analysis, with strong theoretical and practical backgrounds in the field. The document presents some high-level principles that should be used for ensuring prudent risk analysis. It is referred to as a discussion document, as it acknowledges that what is included represents a choice made by someone, and others could have argued for other formulations and principles. It also acknowledges that the document needs to be subject to continuous scrutiny, as scientific progress requires reflections and critical research on current ideas and beliefs. Nonetheless, the principles can be considered to have a strong justification and represent the most warranted statements today from the perspectives of a broad group of risk analysis scientists.

As an example of a principle from the SRA [43] document, consider the criteria related to defining a high-quality scientific risk assessment:

i) It meets some basic scientific requirements

a. It is solid.
b. It is relevant and useful.
c. It is reliable and valid.

ii) The decision-maker (and other stakeholders) has confidence in the assessment and its results and findings.

Here reliability is related to the consistency of the 'measuring instrument', whereas validity relates to 'measuring' what one sets out to 'measure' in the analysis. There are challenges in relation to both criteria, as discussed for example by Aven and Heide [7] and Aven [2]. For example, suppose the aim of the assessment is to provide a comprehensive description of risks in a municipality. A risk assessment is conducted, and the overall risk presented is in the form of an expected loss, which is in fact a rather common metric used in risk assessment. Certainly, such a risk assessment would not meet the validity criterion in this case, as the expected loss does not provide a broad characterisation of risk. The metric fails in two ways. Firstly, it does not reflect aspects of the relevant probability distributions beyond the centre of gravity. Secondly, it gives no information about the knowledge supporting the metric. This knowledge could be strong or poor, but this is not captured by the metric. See Paté-Cornell [32], Haimes [14], Aven [3] and Aven and Renn [8] for further discussions of the limitations of the expected value in describing risk.

As another example, consider a case where the assessment is presumed to present an objective risk characterisation. However, the assessment would then fail to meet the reliability criterion, as different assessments would produce different results. If, on the other hand, the aim of the risk assessment is to present the knowledge of the assessors, it would be acknowledged that the results would be subjective or intersubjective. Consistency in the measuring instrument would then have a different meaning. The results should obviously not depend on who performs the computer calculations or calculates the probabilities, but the reliability criterion would not be violated just because the presented risk description depends on the assessors, as long as the assessment adequately reflects the uncertainties and knowledge of the assessors. What is 'adequate' is a topic for discussion, but key criteria exists (see e.g. [7]), for example that coherent uncertainty assessment is achieved using the rules of probability theory.

As a last example, consider the need for precise definitions of key concepts. If the risk assessment is not built on well-defined concepts, the assessments fail in relation to the requirement of solidness (i)a), but the validity criterion is also challenged, as it reflects the degree to which the risk assessment describes the specific concepts one is attempting to describe. For example, if probability is used in the risk measurements, a lack of proper understanding of this concept could easily lead to poor uncertainty characterisations. The analysts may consider the probability used to represent all the uncertainties present and ignore ambiguity and imprecision issues, as well as the knowledge supporting the assignments.

These examples relate to risk assessment. Other types of criteria can be formulated for other aspects of risk analysis such as risk management and governance. As an example, consider the SRA [43] requirement:

> The process of balancing different concerns can be supported by cost-benefit methods, but this type of formal analyses needs to be supplemented with broader judgements of risk and uncertainties, as well as stakeholder involvement processes [43].

In many types of applications, we see that cost-benefit analysis is used to prescribe what to do, but this requirement clearly states that this practice is not in line with prudent risk analysis, as risk and uncertainty are not adequately reflected in the cost-benefit analyses. In fact, these analyses are based on expected values.

3. Why scientific risk analysis quality is essential for ensuring good risk communication

In this section we will discuss in greater detail the link between scientific risk analysis quality and risk communication. The examples introduced in Section 1 are first looked into. Then a more general discussion is provided.

3.1. The IPCC risk communication

The IPCC aims at informing governments and decision-makers at all levels about scientific knowledge about climate-change issues. Their work is, to a large extent, about risk. The communication can be viewed as successful in the sense that most governments are now taking serious actions in line with the main conclusions made by the IPCC. However, the scientific quality of the risk assessments and characterisations made can be questioned, and hence also the related risk communication.

Risk and probability are fundamental concepts in the IPCC work. However, clear definitions are not provided. As referred to in Section 1, it is a key message of the IPCC that it is very likely that the global warming trend is a result of human activities. A probability of 95% is used to express this, but no interpretation is presented. The concept of risk in the IPCC works refers to probability but with no interpretation of probability; also, the concept of risk become undefined and vague. Equally important, significant aspects of risk are not really communicated. The point being made is that, to be used in relation to climate-change issues, a probability has to be viewed as a subjective (also referred to as a judgemental or knowledge-based) probability, which is conditional on some knowledge. This knowledge can be more or less strong and even erroneous. This fact creates two additional dimensions of risk: firstly, a need for characterising the strength of this knowledge and, secondly, a need for considering surprises relative to the knowledge available [42,43,8]. The IPCC works are not explicit on these dimensions, although the former is discussed in relation to statements when referring to evidence and agreement among experts. The problem is, however, as was mentioned in Section 1: there is no link between the probability judgements and the strength of knowledge judgements in the IPCC framework. From this perspective, the risk analysis science clearly shows that there is such a link and it is essential for understanding risk [42,43,8].

Most governments and decision-makers seem to trust the IPCC and its scientific results and find the IPCC to be a credible source for communicating the climate-change-related risks. The concerns raised by risk analysis have not influenced this trust and credibility. It can be argued that these concerns are not of a significance that changes the overall important conclusions from the IPCC: rather, they should be

seen as details on a technical level.

However, this type of reasoning is easily rebutted. It represents a dangerous attitude to science, which per definition, seeks at identifying and using the most warranted statements and beliefs that the knowledge disciplines can produce [15,16]. Risk analysis is a key science in relation to all types of risk knowledge generation, including climate-change-related risk. One of its main focus areas is risk conceptualisation and characterisations. It provides authoritative guidance – the key principles – on how risk should be best described to inform decision-makers and other stakeholders. Violations of these principles can strongly influence the way risk is understood.

For example, when using the term 'probability of 95%' to express that it is very likely that the global warming trend is a result of human activities, it matters a lot whether this is a statement reflecting some objective physical phenomena in the world or whether it is the view of some experts. The IPCC is not clear on this point but indicates in a rather imprecise way that the probability is linked to variation and thus some physical phenomena. This type of interpretation gives the probability statement a stronger scientific basis than if we are to interpret the probability as a subjective probability (see the coming paragraph for an interpretation). Although the latter type of probabilities can be given a rigorous foundation [27], it represents a challenge in risk communication as it is a judgement made by someone.

Openness and traceability on such matters characterise prudent risk analysis. However, these issues are not discussed in the existing IPCC documents. There is no reason to believe that the current imprecision on key concepts in these documents is a deliberate policy to strengthen the objective authority of the IPCC findings. However, the imprecision opens the door to legitimate criticism, as the 'objective variation type of interpretation' is not justified. In fact, on the basis of the scientific risk analysis work referred to, the risk analysis science would conclude that it cannot be justified, as there is no objective foundation for such a probability in a case like this. Subjective (knowledge-based) probability is the only one that can be meaningfully defined. According to this thinking, the IPCC has a strong belief that the global warming trend is a result of human activities, but it must be acknowledged that this is a belief conditional on some other beliefs (knowledge). It does not mean that the statement is true in 95 out of 100 cases, as is often used to explain probabilities. This type of interpretation has no meaning in this context. Rather, we must think of the uncertainty and degree of belief as comparable with drawing a red ball randomly out of an urn comprising 100 balls, of which 95 are red. The interpretation does not reflect any type of variation or features of the real world, although variation and such features can be used as input to the judgements of the uncertainties.

On this basis, it can be claimed that the current IPCC risk communication misinforms decision-makers and other stakeholders. The risk communication fails from a risk analysis perspective.

Solidity is a basic requirement for a prudent assessment, as was discussed in Section 2. Not being precise on the meaning of key concepts violates this requirement. This is not about semantics as such but about the fundamental risk thinking that has considerable influence on how the results and findings of the IPCC work are reported and communicated. It is also about lack of validity, as the aim of the IPCC work is to adequately characterise risk. Important aspects of risk are not explained nor addressed, as discussed above and in greater detail in Aven and Renn [8].

Probabilities are thoroughly discussed in the risk communication literature (see e.g. [9,10,45]). People have problems in understanding probabilistic type of information. It can be questioned whether increased conceptual precision is leading to improved risk communication. Clearly the context and situation considered matter. Communicating with decision makers is different than with public. Yet the present paper argues that it is essential that the science of risk analysis provides authoritative guidelines for proper understanding and communication of probability. The communication related to one of the most important global risks (climate change) is today hampered by the current lack of accurate interpretation of the IPCC findings.

3.2. Security risks

Consider as an example the UK Secret Services' approach to expressing threat levels [44]. Five categories are used: "LOW means an attack is unlikely, MODERATE means an attack is possible but not likely, SUBSTANTIAL means an attack is a strong possibility, SEVERE means an attack is highly likely, and CRITICAL means an attack is expected imminently" [44]. In Norway, a similar categorisation is used by the Norwegian Police Security Service (PST): "*Very likely*: There is very good reason to believe, *Likely*: There is reason to believe, *Possible*: About as likely as not, *Unlikely*: There is little reason to believe, *Very unlikely*: There is very little reason to believe" [34].

Now, suppose a case where the assessor's belief that an attack will occur is considerable but far from 50%, and the supporting knowledge is very strong. How should the assessor classify and communicate this? Using the above systems is difficult. Of course, any classification system would have weaknesses and limitations, but the current systems mix likelihood judgements and the knowledge supporting these judgements. The result is confusing terminology and communication. An attack is always possible, and what does strong possibility mean? Using subjective (knowledge-based) probabilities – preferably as intervals – as referred to in the previous section, clarity can be obtained, as well as more informative communication. The assessors' judgements are based on the available intelligence and possible attackers' capabilities and intentions, but, using the current classification systems, the strength of this information and knowledge is not communicated to the public in an informative way – important aspects of risk are suppressed. We again see how risk analysis insights are important to ensure good risk communication.

3.3. Industry safety case

We return to the industry example introduced in Section 1. In this case, all involved parties found the risk communication successful in all respects, but, nonetheless, there could be reasons to question the quality. The public and decision-makers did not have the competence needed to challenge the risk assessments conducted. The overall perception is that the risk assessment and related management processes are conducted in line with well-established standards, like the ISO 31000 on risk management. There are no incentives for the operator and consultancy company to see beyond these standards and their own in-house procedures.

There may, however, be a gap between this practice and the scientific knowledge on risk assessments. This gap can be unknown to the consultancy company or not acknowledged as a gap. Their authority as a recognised consultancy company would suffer if it became known that the approach adopted is not in accordance with the best available scientific insights. The result is that weaknesses and delimitations of the assessment approaches and methods are often suppressed.

To meet this challenge, the relevant safety agency has a responsibility. It needs to be updated on current scientific developments. However, in practice there is often a considerable delay between the knowledge of the scientists and the regulations and industry practice. Also, the agencies may face a dilemma by acknowledging that important scientific findings on how to conduct the risk assessments exist but not implementing them in official regulatory documents. The implications are often that the agencies are also passive in relation to questioning the practice of the consultancy companies ([2], p. 13).

A debate on the risk analysis approach can still arise, as members of the public may be unhappy with the conclusions of the risk management and start to look for ways of questioning its rationale. Then experts on risk analysis are contacted, often resulting in their finding problematic issues linked to the approach and methods used. The gap

between science and practice is pointed to. There could be various motives for these experts to be involved and let their voice be used for challenging the consultancy companies, but usually their judgements add alternative and new perspectives to the understanding of risk as presented by the consultancy and operator. Here is an example, inspired by discussions in Aven [2]:

The consultancy and operator communicate that the plant is safe by referring to a derived risk level expressed in the form of probabilities of undesirable events. The argumentation is that the plant has no unacceptable risks. However, as discussed in the previous section, risk is in general poorly described by reference to probabilities alone. The probabilities can be based on a more or less strong knowledge, and this strength also needs to be considered and communicated along with the probabilities. In addition, the fact that surprises can occur relative to current knowledge also needs to be addressed, as the public are those that will be exposed to these. Not addressing this issue, as often seen, means camouflaging important aspects of risk. The public is not properly informed about the risks. The risk communication fails in informing the public [4,42,43].

In most cases, the public will not have the competence to challenge the consultancy companies and operators, as the risk assessments are technical and use terminology which is difficult for lay persons to understand. Yet, the risk communication cannot be judged as successful just by observing that all relevant parties are pleased with the approach taken or do not have reasons to question it. The risk analysis science is also a relevant party and needs to be included when making judgements about the quality of the risk communication.

3.4. Discussion

Moser [29] provides an informative review of fundamental research findings on risk communication as applied to climate change. The author distinguishes between three main categories of communication purposes. The first one concerns informing and educating people about the issue, here climate change. The second purpose is to obtain some type and level of social engagement and action, whereas the third category aims at bringing about changes in social norms and cultural values that act more broadly. Only the first one is addressed in the current paper. The other two categories are interesting from a risk communication point of view, given the stated purpose, but defining these purposes is founded on value judgements that extend beyond the science of risk analysis.

Research on risk perception and communication has clearly demonstrated that understanding risk requires more than informing and educating people about risk estimates [33]. Such estimates are not enough to bring lay people understanding of risk in line with scientists' expectations. To affect people's behaviour is even more difficult. We know that people's risk perceptions and related decisions are affected by a number of factors and also feelings [13,33,40], but this discussion is outside the scope of the present paper. Here, the focus is on the scientific understanding of the concept of risk, not on how people choose to react to this risk. An interesting question is whether an enhanced risk science and related risk communication would have the potential to provide people with an improved scientific risk understanding and establish a stronger separation between people's scientific risk understanding and what are perceptional aspects. Surely, simply characterising risk through some probability numbers would create a gap between people's risk characterisation and their intuitive risk understanding, the result easily being that this 'risk gap' is mixed with the risk perceptional factors when trying to explain people's attitude to risk.

The critical issue seems to be that important aspects of uncertainty are not captured by current risk conceptualisations and characterisations. The industry example illustrates this clearly. The professional risk descriptions and related communications highlight probabilities and statistical expected values, and risk considerations beyond these are judged by the risk analysis professionals and the industry – often also the safety authorities – to be highly subjective risk perceptions of a different value and importance, compared to the 'objective' risk characterisation produced by the scientists and analysts. However, the current risk analysis literature provides strong support for the acknowledgment that uncertainty is a main component of risk, and people's judgements of risk can thus be far more informative than a narrow probabilistic representation and communication of risk [41–43].

An illuminating security application is presented in Aven [5]. Here, historical data are used as a reference for the risk considerations, and it is argued that, if risk is assessed as higher than is indicated by the data, it is irrational and perceptional aspects like fear are dominating the judgements. However, people's judgements in the situations considered can equally be seen as serious deliberations of the uncertainties and risk, where perceptional aspects like fear are not an issue at all. Depending on the perspective taken, the risk communication will be completely different. The present author argues that only the latter perspective represents prudent risk analysis [5].

The same type of discussion is also relevant for the climate-change case. Here, the uncertainties are clearly acknowledged and communicated by the IPCC but based on characterisations, which are not complete and convincing. Firstly, probabilities are referred to, which are not well-defined, giving the impression that these probabilities are more scientific than can be justified. Secondly, the strength of the knowledge supporting these probabilities is not described, as the IPCC framework fails to link probability judgements and knowledge. Consider the following example from IPCC [20]:

"The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1 °C (low confidence) but less than about 4 °C (medium confidence) of global warming with respect to pre-industrial temperatures" [20].

Low confidence is based on a judgement of evidence and agreement among experts. As the confidence is low, it is in place to ask what this statement means. Does the IPCC believe that the former statement (with low confidence) is true or not? As there is no likelihood linked to the statement, its message is difficult to understand and communicate. The risk analysis as discussed in Section 2 would argue that the problem is that uncertainty is not adequately conceptualised and described, leading to severe risk communication problems.

The above critique of established standards and practice should not be interpreted as expressing that these are not at all science-based. Many of the analysis tools used are the results of decades of scientific development. For sure, many analysts are also fully aware of the limitations of their studies and seek reporting and communication reflecting these limitations. Yet there is reason to question the current practice as the above examples illustrate, and that is what the current paper does.

The present paper refers to documents from the Society for Risk Analysis (SRA), as examples of guidance for good (prudent) risk analysis. However, as commented in Section 2, there will always be a discussion what prudent risk analysis is. Science means to always scrutinize current thinking and beliefs, and seek new knowledge and improvements. We need to balance confidence – believing in some current ideas, principles and methods, and at the same time be humble and open for new ideas and developments.

We return to the question made in the introduction section whether the SRA principles will be more successful in guiding risk analysis than earlier attempts. As a response to this question, it is essential to acknowledge the importance of science and knowledge generation in general. Earlier guidance reflected the then state-of-the art knowledge of the field, and through this the risk analysis practice was improved. However, science is not static. New knowledge is produced and so also for risk analysis. The SRA principles represent one contribution to this knowledge base, and together with others it will influence the practice of risk analysis. The degree this will happen is difficult to assess, but scientific practice shows that over time improvements are made. There

are many conditions and factors that are important in this respect. The present author will argue that the key one relates to the development and acceptance of risk analysis a science per se, refer discussion in Aven [6]. Only if such a state can be obtained, the present author believes that we can really obtain the progress needed for the field, as it would mean a different level concerning number of academic positions, study programs and research projects in risk analysis.

4. Conclusions

Successful risk communication can be defined in relation to different purposes. The present paper focuses on the information and education purposes. Although the competence of the risk-communication sources is always an issue when discussing the success of the communication, the dependencies of the quality of the risk analysis as such are seldom addressed. The present paper has pointed to this fact and provides discussions and examples illustrating the problem. The main conclusions of the discussion are summarised in the following items:

1. Scientific and foundational issues of risk analysis are critical for the successful communication of risk.
2. What is prudent risk analysis needs to be given more attention, in both the scientific literature and in relevant societies like Society for Risk Analysis (SRA)
3. There is an urgent need for establishing basic criteria for high quality risk analysis to guide risk communication.

Applied risk analysis is to be guided by the science of risk analysis, on which concepts, principles and approaches to use, to adequately analyse and communicate risk in practical cases. There will be and should be a continuous debate about what constitute these concepts, principles and approaches, but, at a specific point in time, the discipline of risk analysis needs to define and communicate what is its current knowledge. The work by SRA on these issues is considered a promising start for such a development.

Risks and uncertainties are dealt with in practice, in applications like medicine, engineering and climate change, despite theoretical debates about concepts and principles. The understanding of the fundamental concepts may vary among groups, for example between laypeople and experts, but also within these groups; yet decisions are made. There are obviously different views among risk analysis experts - for example between one of the reviewer of this paper and the present author – what should be the key pillars of the risk analysis field and science. Such disagreement there will always be in a scientific environment; it is in fact a guarantee for the field and science to work as it should. Nonetheless specific risk analysis guidance is needed. The present paper provides such guidance on the basis of some type of reasoning (to large extent founded on work conducted by broad expert committees on risk analysis within SRA). For the risk concept the overriding elements are i) consequences of the activity studied and ii) associated uncertainties, and probability a term used to describe this uncertainty, which leads to consideration of the supporting knowledge and potential for surprises relative to this knowledge. Other guidance references exist and the present author welcomes the continuous discussion on what are the most warranted statements of risk analysis, in line with the basic idea of scientific development, see Section 2.

The rather critical points made on the treatment of risk and uncertainty related to the IPCC work should not be interpreted as an expression of scepticism toward the main insights from the IPCC climate-change reports or even misjudged as taking a critical position towards the major assumption of anthropogenic climate change. This is not the author's field of expertise. The motivation for the critique is to contribute to improving the work on assessing and handling risk and uncertainties in general and related to climate change in particular.

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